

PB84-141563

Fabric Filter System Study
Third Annual Report

Southwestern Public Service Co., Amarillo, TX

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Jan 84



PB84-141563

EPA-600/7-84-002
January 1984

**FABRIC FILTER SYSTEM STUDY:
THIRD ANNUAL REPORT**

by

K.L. Ladd, R.L. Chambers, O.C. Plunk, and S.L. Kunka

Southwestern Public Service Company
P. O. Box 1261
Amarillo, Texas 79170

Contract No. 68-02-2659

EPA Project Officer: Dale L. Harmon

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/7-84-002	2.	3. RECIPIENT'S ACCESSION NO. PB8 4 14156 3
4. TITLE AND SUBTITLE Fabric Filter System Study: Third Annual Report		5. REPORT DATE January 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) K. L. Ladd, R. L. Chambers, O. C. Plunk, and S. L. Kunka		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southwestern Public Service Company P. O. Box 1261 Amarillo, Texas 79170		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-2659
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Annual; 9/79 - 10/80
		14. SPONSORING AGENCY CODE EPA/600/13
15. SUPPLEMENTARY NOTES IERL-RTP project officer is Dale L. Harmon, Mail Drop 61, 919/541-2925. First two reports in this series are EPA-600/7-79-183 and -81-037.		
16. ABSTRACT The report gives results of the third year of operation (ended October 1, 1980) of a fabric filter installed by Southwestern Public Service Co. on its Harrington Station Unit 2 coal-fired boiler in Amarillo, TX. Results of the emissions testing program demonstrated that the 1971 EPA standard of 1.2 lb SO ₂ /million Btu can be met by burning coal with a sulfur content lower than 0.5 percent. Particulate emissions were less than the 0.03 lb/million Btu standard in all four of the particulate emissions tests. Fabric studies to date show that several fabrics have a potential 3-year baglife. The operation and maintenance cost reported for the third year of study is \$434,800, or \$1.21/yr/kW. Data analysis continued through the third year. Information on boiler O ₂ levels, air-to-cloth ratio, temperature, system pressure drop, and boiler load is being logged continuously.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Boilers Fabrics Sulfur Oxides Dust Coal Combustion	Pollution Control Stationary Sources Fabric Filters Particulate	13B 13A 11E 07B 11G 21D 21B
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 52
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

The third year of work on the fabric filter study being conducted by Southwestern Public Service Company for the U. S. Environmental Protection Agency ended October 1, 1980. Results of the special emissions testing program demonstrated that particulate emissions were less than the applicable 1971 EPA standard of $0.1 \text{ lb}/10^6 \text{ Btu}$ in all four of the particulate emissions tests. Fabric studies to date show that several fabrics have a potential three-year baglife. The operation and maintenance cost reported for the third year of study is \$434,800, or \$1.21/yr/kw. Data analysis continued through the third year. Information on boiler O_2 levels, air-to-cloth ratio, temperature, system pressure drop, and boiler load is being continuously logged.

TABLE OF CONTENTS

	<u>Page</u>
Abstract	iii
List of Figures	v
List of Tables	vi
Conversion Table	vii
I. Introduction	1
II. Summary and Conclusions	2
III. Summary of Test Program	5
A. Phase II	5
B. Phase III	6
C. Phase IV	8
D. SPS/GCA Test	11
IV. Fabric Testing Results	13
A. Breaking Strength	13
B. Mullen Burst	17
C. MIT Flex	17
D. Failure Mechanisms in Filtration Fabrics	21
E. Causes for "Wooley Worm" Failures	26
F. Relative Flow	31
V. Operation and Maintenance	34
VI. Pressure Drop Performance	38
VII. Operation and Maintenance Costs	40
VIII. Data Acquisition and Assessment	41
A. Collection of Data	41
B. Monthly Average Full Load Pressure Drop	42
IX. References	43

LIST OF FIGURES

<u>Number</u>	<u>Page</u>
1. Summary of Particulate Testing	3
2. Fabric Installation, July, 1979	14
3. Breaking Strength	15
4. Mullen Burst	18
5. MIT Flex vs. Time	19
6. Reduced MIT Flex vs. Time	20
7. Photo, Fold Lines (Removed Sample)	23
8. Photo, Fold Lines (In Compartment)	23
9. Photo, Pinhole Formation Along Fold Lines	23
10. Photo, "Wooley Worm" Failure	24
11. Photo, Horizontal Tear	25
12. Photo, Horizontal Tear (Closeup)	25
13. Photo, Vertical Slit	25
14. Photo, Rectangular Failure	27
15. Photo, Mated Failure	27
16. Photo, Total Destruction by Mated Failure	28
17. Photo, Fiber Damage Along Fold Lines	28
18. Photo, Fiber Breakage (Magnified)	28
19. Photo, Fold Line	30
20. Photo, Closeup of "Wooley Worm" Wear	30
21. Typical Failed Gear Nut (Inside View)	35
22. Typical Failed Gear Nut (Outside View)	36
23. Monthly Average Full Load Pressure Drop	39

LIST OF TABLES

<u>Number</u>	<u>Page</u>
I. Phase II Test Results	7
II. Phase III Test Results	9
III. Phase IV Test Results	10
IV. Results of SPS/GCA Special Testing	12
V. List of Fabrics	16
VI. Averages of Relative Flow	32
VII. Operation and Maintenance Costs	40
VIII. Instrumentation and Data Collection	41
IX. Correlation Matrix	42

CONVERSION TABLE

To Convert From	To	Multiply by
Btu/lb	joules/kg	4186.8
°F	°C	(°F-32)/1.8
ft	m	0.305
gr/scf	gm/m ³	2.29
in.	cm	2.54
in w.g.	mm Hg	1.87
lb	gm	454
miles	km	1.609
oz.	grams	28.350
ppm	mg/liter	1.0
Btu	joules	1055
cfm	cubic meters/hr	1.699
ft/sec	centimeters/sec	30.48
sq. ft.	sq. meters	0.093
lbs. of tension	newtons	4.448
stack pressure in Hg	kg/cm ²	0.035
wscf/10 ⁶ Btu	wscm/joule	2.6×10 ⁻¹¹
lbs/10 ⁶	nanogram/joule	433.3
lbs/wscf	micrograms/m ³	16.018×10 ⁸
ft ²	meters ²	0.093

I. INTRODUCTION

The third year of work on the fabric filter system study being conducted by Southwestern Public Service Company (SPS) for the U.S. Environmental Protection Agency (EPA) ended October 1, 1980. The overall objective of this project is to make a comprehensive study of a fabric filter system used for particulate collection on an electrical generating unit that utilizes low sulfur, western coal.

SPS is an electric utility headquartered in Amarillo, Texas. The Company has a generating capability of 3162 Mw and serves customers in Texas, Oklahoma, New Mexico, and a small portion of Kansas. Harrington Station, where the study is being performed, is SPS's first coal-fired plant. Located 8 miles northeast of Amarillo, Harrington went into operation in July, 1976. Three units are now on line and construction is underway on SPS's second coal-fired plant, Tolk Station. Tolk Station will also be equipped with fabric filters for air quality control.

Project activities during the third year of the study included completion of the special testing phase, analysis of fabric testing results, observation of operation and maintenance parameters, and continued data collection. The first and second annual reports describe the objectives and background of these project activities (1, 2).

The fabric filter system for Harrington Unit 2 is a Wheelabrator-Frye, Inc. structural baghouse with deflate and shake cleaning. It first went on line in June, 1978. The baghouse consists of 28 compartments with 204 bags per compartment for a total of 5,712 bags; each bag is 11½ inches in diameter and 30 feet, 8-¾ inches long at 60 pounds tension. The baghouse was specified to operate at 1,650,000 acfm of flue gas at 313°F, thus yielding an air-to-cloth ratio of 3.15 to 1 (gross) or 3.4 to 1 (net).

II. CONCLUSIONS

1. Special testing of emissions was performed four times during the reporting period. Three of the emissions tests were done by SPS and the fourth was performed jointly by SPS and GCA. Particulate sizing at the inlets and stack was attempted during the SPS/GCA test.

The results of the special testing program showed that the stack emissions of SO_2 agreed very well with theoretically calculated emission levels. The consistency between the measured and theoretically derived numbers also indicates that EPA Method 6 is a reliable and accurate measurement technique for SO_2 determination. The emissions measured were in the range of 0.78-1.01 lbs SO_2 $10^6/\text{Btu}$, demonstrating that the existing EPA standard of 1.2 lbs SO_2 $10^6/\text{Btu}$ can be met by burning coal with a sulfur content lower than 0.5%.

Particulate emissions from the Unit 2 fabric filter system were less than the applicable standard of 0.1 lb/ 10^6 Btu in all five of the particulate emissions tests done to date. Results (see Figure 1) show that the average of each of the test series is below both the 0.1 lb/ 10^6 Btu standard and the new 0.03 lbs/ 10^6 Btu standard but uncomfortably close to the lower limit with 7 of the 18 individual data points equalling or exceeding the 0.03 lb/ 10^6 Btu level. (Compliance with emission standards is based upon the average of the individual test runs).

2. In the summer of 1978 the Harrington Unit 2 fabric filter system was rebagged with a variety of fabric types to allow a study of baglife and fabric wear. The results of this program have shown that several of the fabrics have a potential three-year baglife. The study also demonstrated that a Teflon-coated 10-oz. fabric outlasted a heavier 14-oz. acid-resistant fabric. Studying the shaking motion of these fabrics during cleaning revealed that the stiffness of the 10-oz. fabric and the extra lubrication offered by the Teflon coating contribute to its longer baglife.

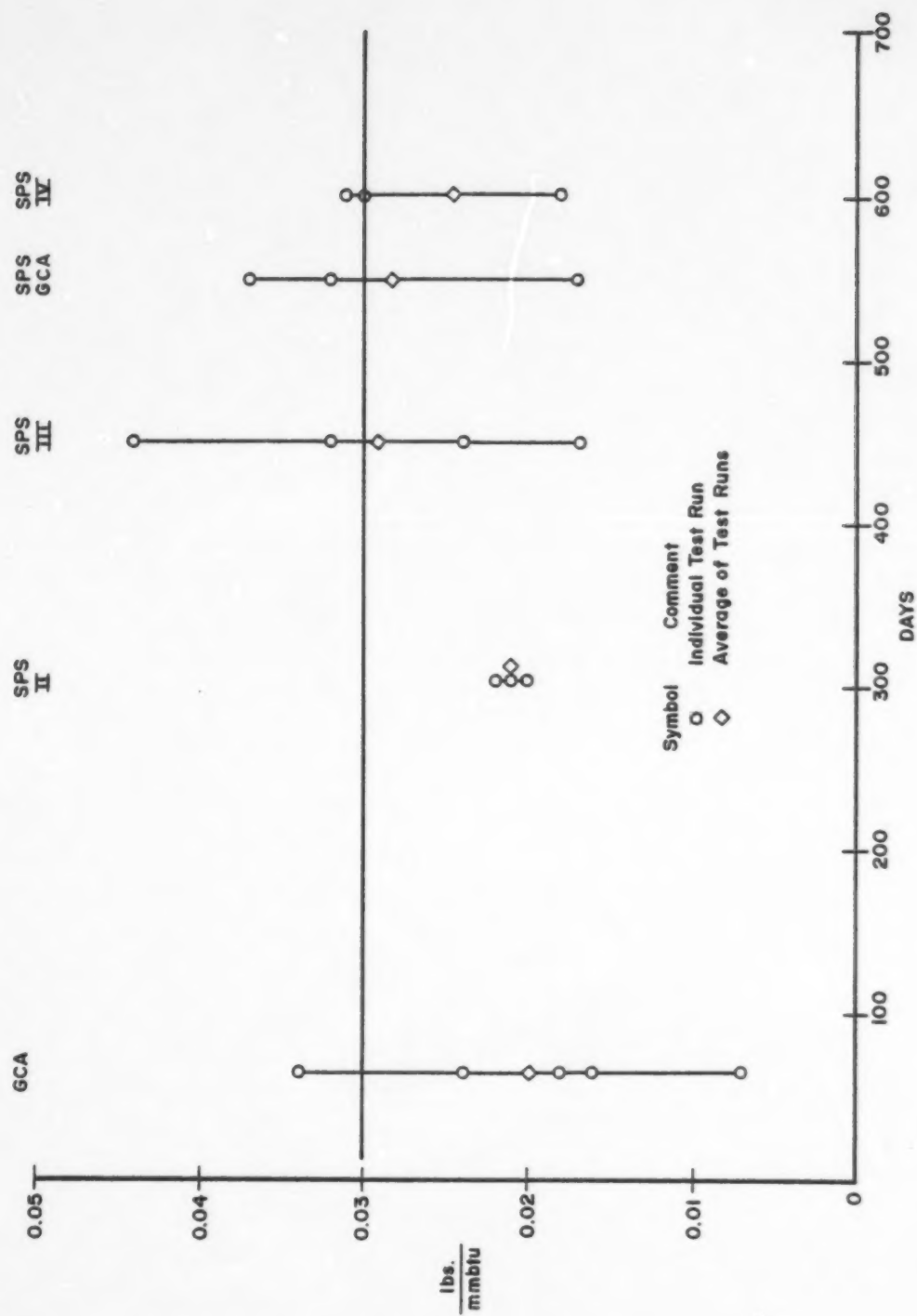


Figure 1. Summary of Particulate Testing

3. The operation and maintenance problems occurring during the third year of the study include four main areas:

1. Shaker tube flangette bearings.
2. Sagging shaker tube supports.
3. Damper drive failure.
4. Fabric failure.

The first two items are a result of inherent design and once corrected, should not continue to be a source of maintenance effort. The third item, damper drive failures, has been in large part due to some machining and lubrication problems. Damage to the dampers and drive mechanisms has occurred in some cases due to overdriving the mechanism after a limit switch has failed.

The fourth item involved only a few compartments containing a 14-oz. silicone/graphite-coated fabric that failed prematurely. This experience, plus an analysis of the reaction of various fabric types to the shaking motion and interpretation of fabric testing data, indicates that the 14-oz. silicone/graphite-coated fabric is not suitable for either of Harrington's baghouses.

5. The operation and maintenance cost reported for the third year of study is \$434,800, or \$1.21/yr/kw. This figure is somewhat higher than the expected average because it includes redesign and modifications that will not have to be repeated on an annual basis.

6. Data analysis continued through the third year of study. Information on boiler O_2 levels, air-to-cloth ratio, temperature, system pressure drop, and boiler load is being continuously logged at Harrington. Analyses have shown that these variables are highly correlated and that modeling attempts will require sophisticated statistical methods.

III. SUMMARY OF TEST PROGRAM

A major objective of the SPS/EPA study is to characterize gaseous and particulate emissions from the boiler/baghouse system. During the second year of study, Phase I of a special testing program was implemented and completed. Results of the first test are shown in the Second Annual Report (2). A special report describing the overall test program was published in October, 1981 (3).

A. Phase II

The second series of special tests to be performed by SPS was initially scheduled for May, 1979. Due to a decision to rebag the fabric filter system, special testing was rescheduled for October 8-12, 1979.

In September of 1978, the Harrington Station baghouse began to experience a higher than normal failure of bags. Examination of the problem indicated that two items needed immediate attention: (1) the control of the deflation pressure during the cleaning cycle and (2) lack of proper bag tension. By October, a program had begun to redesign the deflation pressure control system and attempts were made to retension the bags.

The bag failure rate continued to accelerate in the Unit 2 baghouse, which was of great concern to SPS. These failures were of two types; small pinhole-type failures near the bottom cuff, and failures described as "blowouts" where a whole section of the bag would burst and fray. Based on information derived from an in-house fabric assessment program and an EPA mobile baghouse study (4), SPS decided that the original fabric was inferior and would have to be replaced. SPS rebagged the entire baghouse with new fabrics before the 1979 summer peak.

Another adjustment that resulted from the EPA mobile baghouse study was resetting the cleaning cycle and increasing the frequency

of shake on two compartments. The adjustment in frequency of shake was accomplished by changing the size of the shaker's drive mechanism pulley.

A relative flow comparison between compartments with a standard shake and an accelerated shake indicated much improvement in cleaning and pressure drop. Larger pulleys were placed in additional compartments and two problems resulted: (1) the limitation of shaker motor horsepower could not be exceeded and (2) the shaker pillow block system began to fail. It was determined that a 5.3-inch pulley in place of the 4.0-inch pulley provided enough frequency increase and was within horsepower limitations. The pillow block assemblies were redesigned and replaced before the second special test; no recent problems have been noted.

With these changes having been completed, SPS conducted the Phase II special testing in October, 1979. The experience gained in the first series of tests enabled SPS personnel to conduct tests at all five sample locations as originally specified by the EPA. Results of the Phase II testing are shown in Table I.

Data from the outlet sample location indicated higher particulate concentrations than data from stack sample locations. This difference may be due to a poor outlet sampling location and an extra long port extension. It was very difficult to sample these locations without picking up fly ash in the 6-foot port extension and a very small quantity can significantly affect the results.

High negative pressure still affected the Phase II SO₂ measurements, although results were much improved over the first test. This problem was attributed to negative pressure pulling the absorbing solution forward in the sampling train.

B. Phase III

SPS's third special test was performed the week of March 24-27, 1980. Twenty SPS employees participated in the week-long test for SO₂ and particulate. A number of difficulties were encountered,

Table I. Phase II Test Results

Results of Particulate Testing:

Run No.	East Inlet gr/scf	West Inlet gr/scf	Theoretical gr/scf±	East Outlet gr/scf	West Outlet gr/scf	Stack gr/scf	Stack lb/10 ⁶ Btu
1	1.40	1.41	1.64	.014	.012	.010	.020
2	1.61	1.41	1.64	.014	.024	.011	.021
3	1.61	.74*	1.69	.027	.028	.011	.022
Avg.	1.54	1.19	1.65	.018	.021	.011	.021

Results of SO₂ Testing:

Run No.	East Inlet lb/10 ⁶ Btu	West Inlet lb/10 ⁶ Btu	Theoretical lb/10 ⁶ Btu	East Outlet lb/10 ⁶ Btu	West Outlet lb/10 ⁶ Btu	Stack lb/10 ⁶ Btu
1	.71	.74	1.03	.70	.76	.79
2	.74	.79**	.95	.79	.82	1.01
3	.66	.71**	.99	.78	.78**	.96
Avg.	.70	.75	.99	.77	.79	.92

± Based upon stoichiometric flue gas flow, coal flow, ash analysis and 70 percent fly ash generation and 30 percent bottom ash and economizer ash generation.

* One sample of probe wash was lost during transport from sample site to the lab, causing this sample to be biased (low).

** Based upon only one of two samples for this run.

causing several delays; however, it was felt that the testing was concluded in a successful manner.

Results of the Phase III testing are shown in Table II. Inlet testing teams had considerable problems with high negative static pressure breaking the fritted supporting disks. This accounts for the low grain loading experienced on the various runs. The last run at the stack location failed the leak test at the end of the run. SPS determined that a connector glassware clamping the hot box lost tension and leaked. A review of the raw data indicates this probably happened at the first point in the last port.

A review of the Phase II SO₂ results indicates that problems still existed with sampling the highly negative pressure ducts with the SO₂ impingers. Improvements in testing procedures had been made by Phase III to stop loss of absorbing solution from the impingers.

C. Phase IV

Maintenance and operation changes between the third and fourth special tests ranged from cleaning boiler slag out of the Unit 2 economizer and air preheaters to repairing shaker tube flange bearings. The bags in compartment 23 were changed out during April, due to multiple pinhole failures in the upper portion of the bags. In addition, seven shaker mechanisms were repaired in June.

During the Phase IV testing periods in August, 1980, the baghouse encountered no major upsets or operating problems. All of the shakers were in service and operating in a normal fashion. The temperatures, flows and pressure drops encountered were all within normal operating limits.

Opacity, however, was higher than normal. Opacity spikes were observed that seemed to correspond with the cleaning cycle of compartment 27. The compartment was left in service throughout the test awaiting more definite indications of failure since the opacity spikes did not follow the clean cut blowout pattern previously ob-

Table II. Phase III Test Results

Results of Particulate Testing:

Run No.	East Inlet gr/scf	West Inlet gr/scf	Theoretical gr/scf**	East Outlet gr/scf	West Outlet gr/scf	Stack lb/10 ⁶ Btu
1	*	*	1.82	.008	.012	.017±
2	1.43	1.35	1.95	.013	.038	.024
3	.97	1.14	2.03	.011	.022	.032
4.	*	1.50	2.04	.007	.020	.044±±
Avg.	1.20	1.33	1.96	.010	.023	.029

Results of SO₂ Testing:

Run No.	East Inlet lb/10 ⁶ Btu	West Inlet lb/10 ⁶ Btu	Theoretical lb/10 ⁶ Btu	East Outlet lb/10 ⁶ Btu	West Outlet lb/10 ⁶ Btu	Stack lb/10 ⁶ Btu
1	.76	.69	.82	.70	.68	.81
2	*	.67	.81	.69	*	.75
3	*	.67	.81	.65	*	.78
Avg.	.76	.68	.81	.68	.68	.78

* No data.

** Based upon stoichiometric flue gas flow, coal flow, ash analysis and 70 percent fly ash generation and 30 percent bottom ash and economizer ash generation (dry basis).

± Not isokinetic.

±± Failed leak check test.

served. On August 29, 1980, the compartment was removed from service and four blown bags and two other damaged bags were replaced.

Problems with sampling SO₂ at inlets were corrected and results were comparable to stack SO₂ (see Table III).

Table III. Phase IV Test Results

Results of Particulate Testing:

Run No.	East Inlet gr/scf	West Inlet gr/scf	Theoretical gr/scf*	Stack gr/scf	Stack lb/10 ⁶ Btu
1	1.64	1.92	1.99	.016	.031
2	1.88	1.67	1.97	.009	.018
3	1.35	1.44	1.96	.015	.030
Avg.	<u>1.62</u>	<u>1.68</u>	<u>1.97</u>	<u>.013</u>	<u>.026</u>

Results of SO₂ Testing:

Run No.	East Inlet lb/10 ⁶ Btu	West Inlet lb/10 ⁶ Btu	Theoretical** lb/10 ⁶ Btu	Stack lb/10 ⁶ Btu
1	.84	.76	.96	.84
2	.89	.79	.94	.95
3	.88	.78	.96	.83
Avg.	<u>.87</u>	<u>.78</u>	<u>.95</u>	<u>.87</u>

* Based upon stoichiometric flue gas flow, coal flow, coal analysis and 70 percent fly ash generation (dry basis).

** Coal analysis on an "as burned" basis with ASTM analysis.

D. SPS/GCA Test

A joint test was conducted by SPS and its subcontractor, GCA Corporation, on June 4, 5, 6, 1980. SPS ran simultaneous tests for particulate and GCA tested for SO_3 and particle size distribution.

SPS testing began at 10:50 a.m. on June 4, 1980. No significant problems occurred during the testing. The east inlet probe liner slipped as the probe was being withdrawn from the duct. This caused the train to fail the leak check; however, it is not believed that results were significantly affected. The test concluded at about 12:30 p.m.

GCA began the impactor testing at the stack location at about 7:00 a.m. Goksoyr-Ross was run for one hour. No condensation occurred in the condenser coil indicating the low concentration of SO_3 . A discussion with GCA indicated that a much longer run on the stack might give better resolution of SO_3 . GCA also began the inlet impactor runs about 12:30 p.m. and expected to run until about 4:00 p.m.

No particular problems were experienced by SPS. In order to collect a larger particulate sample, a larger nozzle was selected for the third run. This allowed a larger sample and minimized problems associated with verifying a small particulate sample. The baghouse experienced failures in a shaker mechanism, resulting in higher pressure drop.

The testing during this joint effort was considered by SPS the most successful of any conducted during the program. The inlet particulate concentrations were not as consistent as desired; this factor can be attributed to the lack of idealness in the sampling location. The inlet SO_2 emissions were consistent and compared very well with the stack results. Results of the SPS/GCA test are summarized in Table IV. A more detailed description of GCA's test program is included in two reports prepared by GCA for SPS (5, 6).

Table IV. Results of SPS/GCA Joint Test

Results of Particulate Testing:

Run No.	East Inlet gr/scf	West Inlet gr/scf	Theo- retical gr/scf**	Stack gr/scf	lb/10 ⁶ Btu
1	*	2.30	2.13	.015	.032
2	1.92	1.86	2.22	.019	.037
3	1.38	1.31	1.95	.008	.016
Avg.	<u>1.65</u>	<u>1.82</u>	<u>2.10</u>	<u>.014</u>	<u>.028</u>

* Invalid Test.

** Based upon stoichiometric flue gas flow, coal flow, coal analysis and 70 percent fly ash generation (dry basis).

IV. FABRIC TESTING RESULTS

Harrington Unit 2 was rebagged with a variety of fabrics following its first year of operation (see Figure 2). This made it possible to closely study the pressure drop behavior and wear characteristics of a number of materials all subject to the same filtration conditions.

In order to examine the various fabrics for wear, samples are removed from each of the test compartments on a periodic basis and sent to Environmental Consultants, Inc., for evaluation. Each sample is subjected to the following tests:

1. Breaking Strength.
2. Mullen Burst.
3. MIT Flex (.03-inch jaw @ 4 lbs.).
4. Loss on Ignition @ 1200°F.
5. Permeability.

According to the testing program conducted by Environmental Consultants for SPS, the weakened area along the most severe fold lines are the ones to be tested for mechanical strength rather than the stronger areas away from the fold lines. SPS believes that testing results obtained in this manner are more representative of the rate of decay in mechanical properties for a material since it will be the weakened areas that will determine fabric life.

A. Breaking Strength

The results of breaking strength tests on the filling yarns for the various fabrics are shown in Figure 3. Each of the points represents the average of all the data taken on that fabric at a particular time. The approach was taken to get an idea of the overall condition of each of the fabrics (see Table V).

The 14-oz. fabrics show much higher initial breaking strengths than the 10-oz. fabrics because of the stronger filling yarn construction. The 14-oz. materials, however, have a more rapid rate of

West Baghouse

1 *	2 *
3 *	4 *
5 *	6 Menardi - Southern Teflon Test Bags
7 1 Nomex All-Spun; 2 Nomex Comb.; 5 Crisoflex 446; 4 Crisoflex 449; Bal. *	8 *
9 * (Warp-In)	10 *
11 *	12 *
13 *	14 *

East Baghouse

15 * *	16 * *
17 * *	18 * *
19 Original bags equipped with special shaker mechanism	20 Fabric Filters All-Filament Teflon
21 Criswell 442 Teflon B Test Bags	22 34 Acid Flex; 34 Tri-Treat Balance: Original Bags
23 Fabric Filters 502 Tri-Treat Test Bags	24 Globe - Albany Nomex.
25 Criswell 449 Teflon B Test Bags	26 * *
27 * *	28 * *

- * Criswell 442 Teflon B; (10.5 oz.) (Rebagging complete).
- * * Criswell 449 Tri-Treat; (14 oz.) (Rebagging complete).

Figure 2. Fabric Installation, July 1979

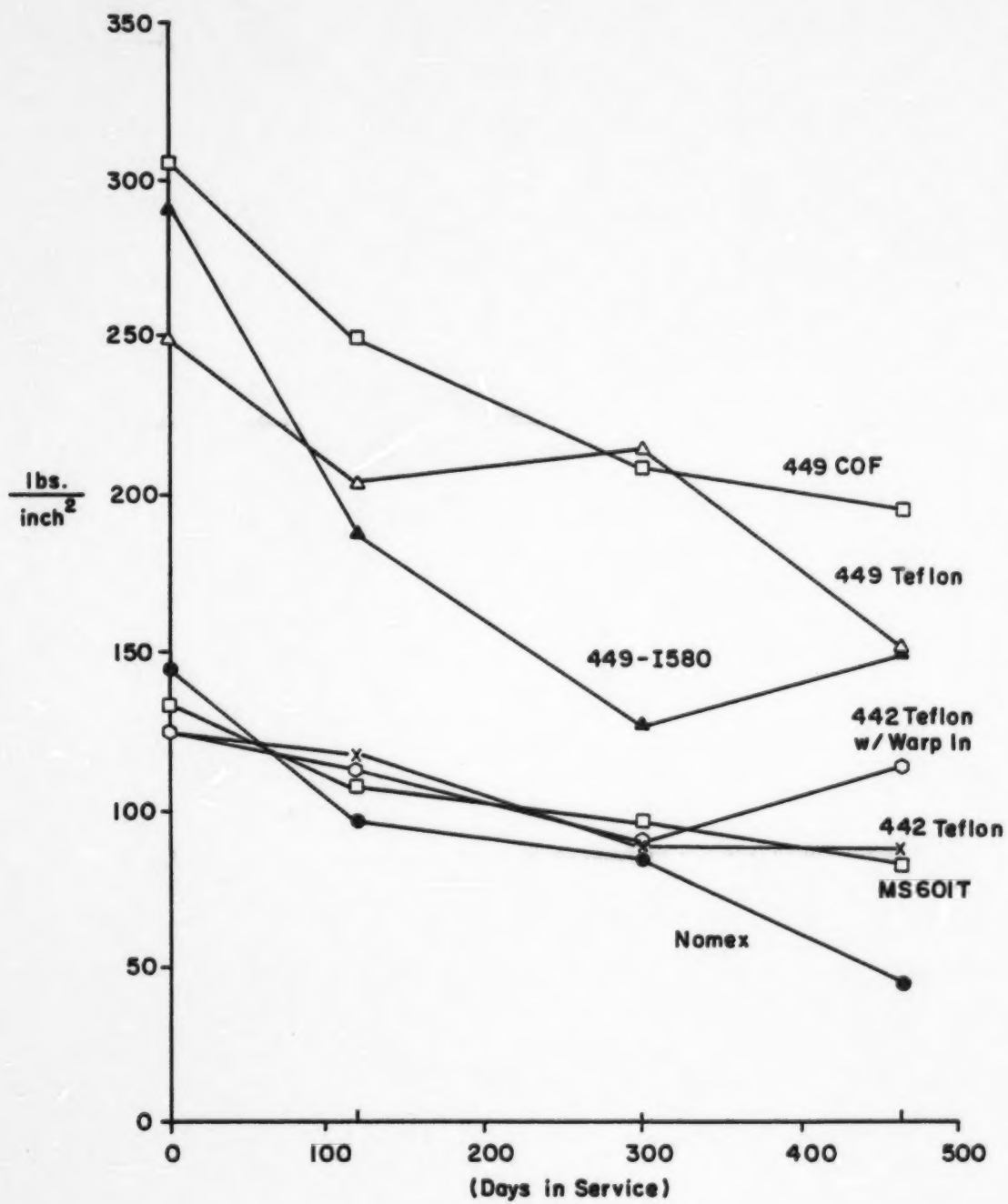


Figure 3. Breaking Strength

Table V. List of Fabrics

Bag Manufact.	Style	Count	Weave	Fill	Weight	Coating
Criswell	449	44x24	37 1/0	75 1/3T	13.5	Cris-o-Flex
Fab. Filt.	502-1	44x24	37 1/0	75 1/3T	13.5	Tri-Treat (Burlington I-580)
Criswell	442	54x30	150 1/2	150 2/2T	9.5	Teflon
Criswell	449	44x24	37 1/0	75 1/3T	13.5	Teflon
Nomex	5-3014	82x72	Allspun	3x2 Twill	6.0	Permaguard
Menardi	601T	54x30	150 1/2	150 1/4	9.5	Teflon

decline in breaking strength than the 10-oz. fabrics. Two of the 14-oz. fabrics, the Criswell 449-COF and Criswell 449-I580, have also had such a high failure rate that they have had to be replaced. The 14-oz. Teflon-coated material, on the other hand, has had very few failures and remains in good condition.

For the 10-oz. fabrics, few failures have occurred and no noticeable differences among their failure rates have been observed. The breaking strength plot suggests that the 14-oz. fabrics are more strongly affected by the cleaning forces than are the 10-oz. fabrics. However, there is no evidence from the breaking strength test results to indicate that two of the heavier fabrics have reached the failure point. In Figure 3 the lowest breaking strength values shown are for a Permaguard-coated Nomex fabric. Being a non-glass fabric, its tensile properties are not as great; however, the fabric has tremendous resistance to flexing. Although Nomex is known to be very sensitive to strongly acidic conditions, it has been undergoing only a very gradual decay at Harrington Station. The low sulfur and alkaline ash content of the coal are thought to be protecting the material.

B. Mullen Burst

Figure 4 shows that the Mullen Burst and breaking strength results are similar in that the 14-oz. materials show higher initial values than the 10-oz. materials and higher rates of decay. The Cris-o-Flex (COF)-coated fabric has the highest value for both breaking strength and Mullen Burst on the unused cloth. This is due to the fact that the fabric has not been heat cleaned prior to application of the coating. Since heat cleaning weakens the fabric to some extent, the COF-finished material has the initial advantage. This advantage is seen to decline, however, as all three of the 14-oz. materials appear to have similar Mullen Burst values after a year in service.

The 10-oz. fabrics are very similar in the Mullen Burst plot. This is undoubtedly due to their very similar construction and the consistency of their Teflon coatings. Nomex is again at the bottom of the plot; the synthetic material lacks the high strength inherent in glass fabrics.

C. MIT Flex

MIT flex values initially fall quite rapidly and then adopt a more gradual linear decline as shown in Figure 5. This linear decline in conjunction with the fact that the MIT flex test most closely resembles the physical wear occurring on the fabric holds promise for the use of MIT flex testing as a useful tool in monitoring fabric wear and predicting bag life.

Figure 6 shows results of the MIT flex tests on the test fabrics. In order to put all these curves on one graph the MIT flex values have been put in reduced form by dividing each test value by the new cloth MIT flex, M_o , yielding a reduced MIT flex value, (M/M_o) . The height of the curves, then do not indicate the differences in absolute values of MIT flex but rather the fraction remaining.

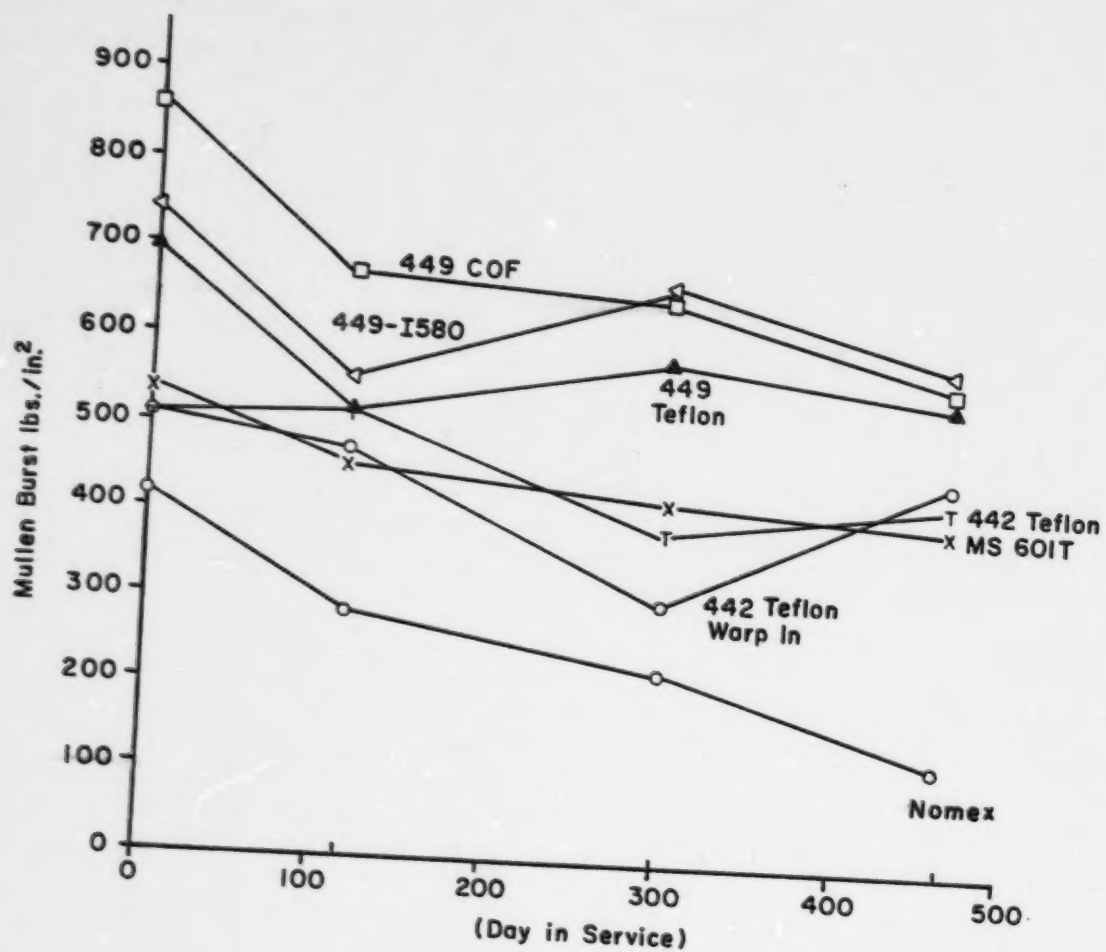


Figure 4. Mullen Burst

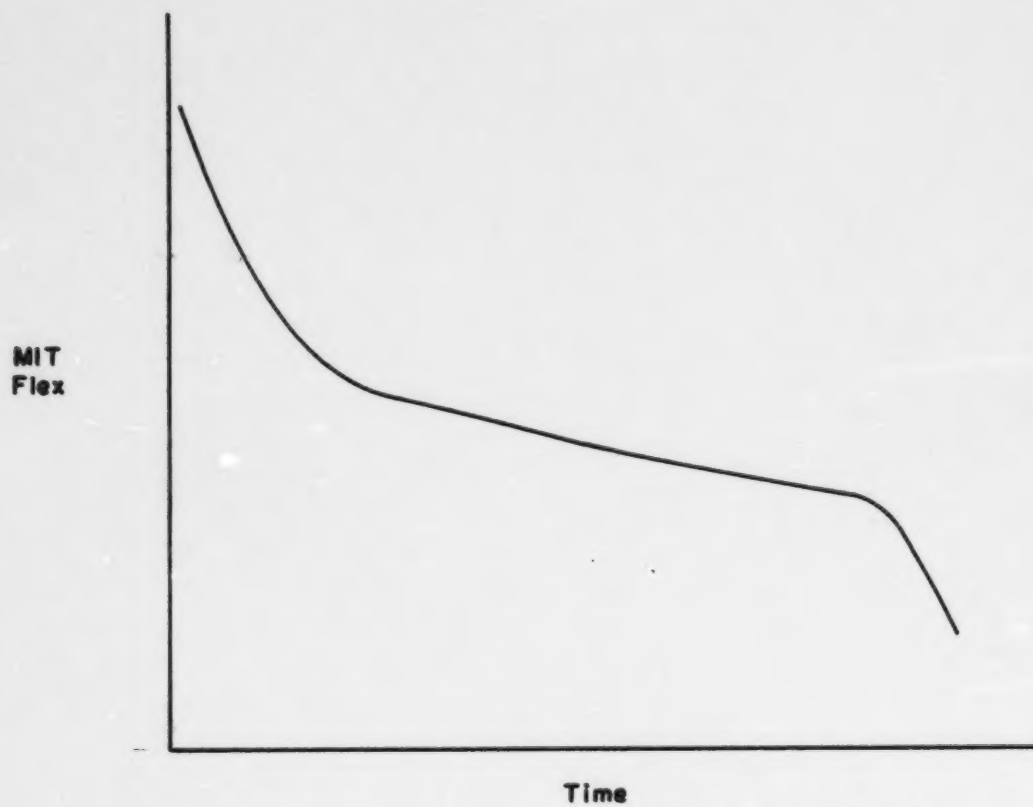


Figure 5. MIT Flex vs. Time

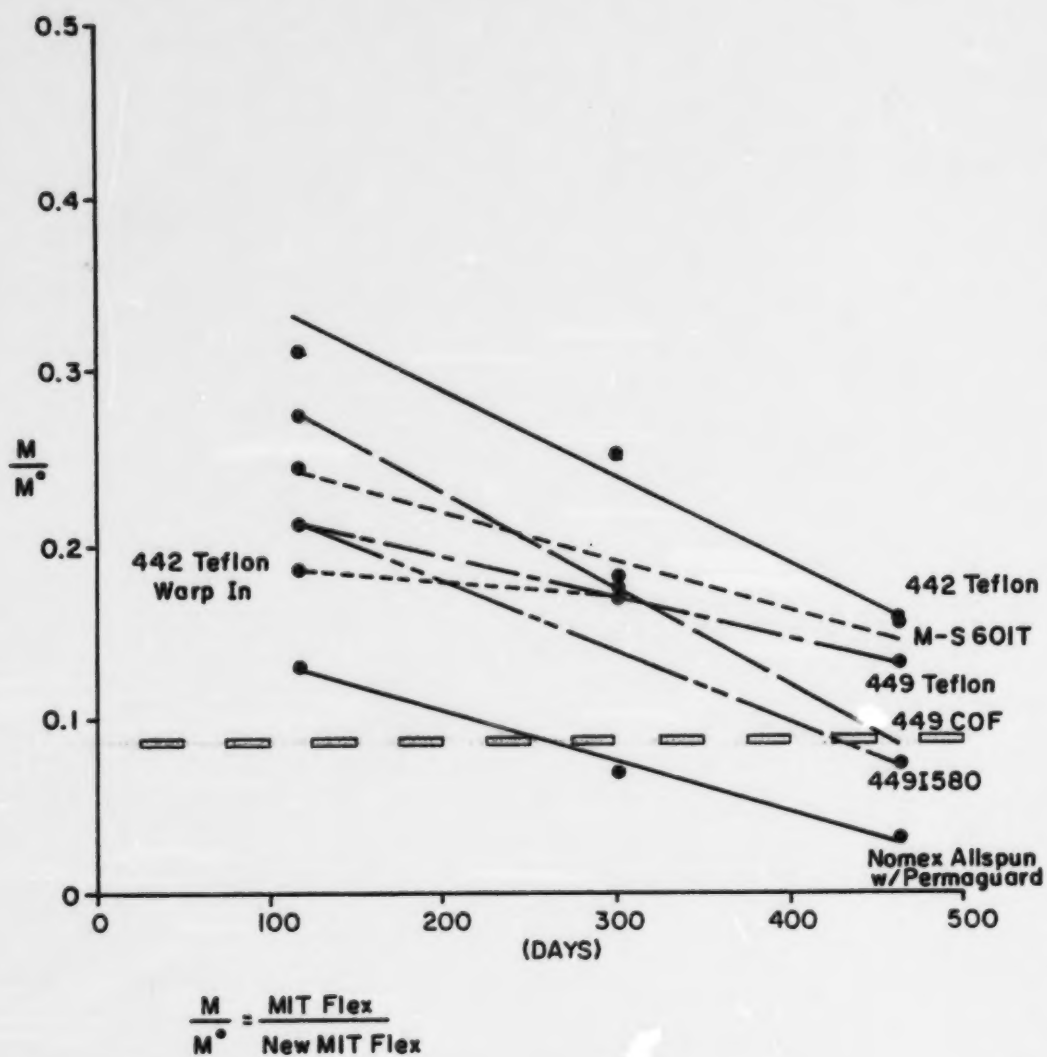


Figure 6. Reduced MIT Flex vs. Time

In contrast to the breaking strength and Mullen Burst plots, the MIT flex plot does show remarkable differences in the fabrics that have failed versus the ones that have not. The steepest decline in flex is shown for the Criswell 449-COF and Criswell 449-I580 materials.

Criswell's 10-oz. Teflon-coated fabric shows the highest (M/Mo) value, but has a higher rate of decline than the other Teflon-finished fabrics. The next two highest reduced MIT flex lines are the Menardi-Southern 601T (which is similar to the Criswell 442 Teflon fabrics), and the Criswell 449 Teflon-finished material. The rate of decline of reduced MIT flex appears to indicate that both of these fabrics should give good fabric life.

The Nomex fabric shown at the bottom of the graph is again a special case since it is not a glass fabric. Nomex is so resistant to flexing that a 5-pound weight is used in the MIT flex test for Nomex instead of the 4-pound weight used with glass fabrics. This additional weight accelerates the relative flex loss. Since Nomex has such high new fabric MIT flex values, it is expected that the value of M/Mo at failure will be much lower than that of other fabrics. Therefore, SPS anticipates that Nomex will give fabric life at least comparable to the Teflon-coated glass fabrics. The experience that SPS has had with Nomex at Harrington is very encouraging due to the material's superior filtration properties compared to glass. In installations with operating conditions similar to Harrington Station, it may be that other fabric filter users will be able to consider utilizing Nomex.

D. Failure Mechanisms in Filtration Fabrics

The fabric testing results just discussed have shown that two of the 14-oz. fabrics being evaluated at Harrington (Criswell 449-I580 and 449-COF) are both undergoing rapid deterioration in MIT flex. These fabrics have experienced high replacement rates in the unit. The replacement rates after 464 days in service are shown below in comparison with Criswell's 442-57DC-2 (Teflon) fabric.

Fabric	Replacement Rate Bags per Compartment
442-57DC-2 (10-oz/yd ² Teflon)	1.1
449-COF (14-oz/yd ²)	5.0
449-I580 (14-oz/yd ²)	7.2

Compartment inspection on the failing fabrics revealed a peculiar dark strip developing along fold lines in the top one-third of the fabric. Typical fabric fold lines are shown in Figures 7 and 8. Two distinct types of fold lines tend to occur. One is a major fold line that extends the full length of the bag. It is common for a fabric to have three such fold lines and thereby adopt a tri-star configuration when fully collapsed. Full collapse of the fabric does not occur unless the fabric is severely overpressured in the deflation mode. Typically, the only time a fabric will be fully collapsed will be when a compartment is opened up and in-leakage past the inlet damper collapses the bags. Properly adjusted, deflation should play no significant role in fabric wear. The other type of fold line is a minor fold line that begins at the top of the fabric and disappears 5 to 15 feet down the bag. These minor fold lines appear to be due to distortion in the fabric by fabric stretch under tension and poor seam registration.

Along any of these fold lines massive fiber breakage has been observed in some fabrics to such an extent that these lines have a "wooley" or "fuzzy" appearance on the 14-oz. fabric. This type of fabric failure has therefore been termed a "wooley worm" type failure. Spaced at intervals down these fold lines, pinholes were observed in the fabric (as shown in Figures 9 and 10). In many cases, on closer examination, the pinholes appeared to be horizontal slits in the fabric along the vertical fold line (see Figures 11 and 12). This occurrence



Figure 7. Fold lines (removed sample).



Figure 8. Fold lines (in compartment).

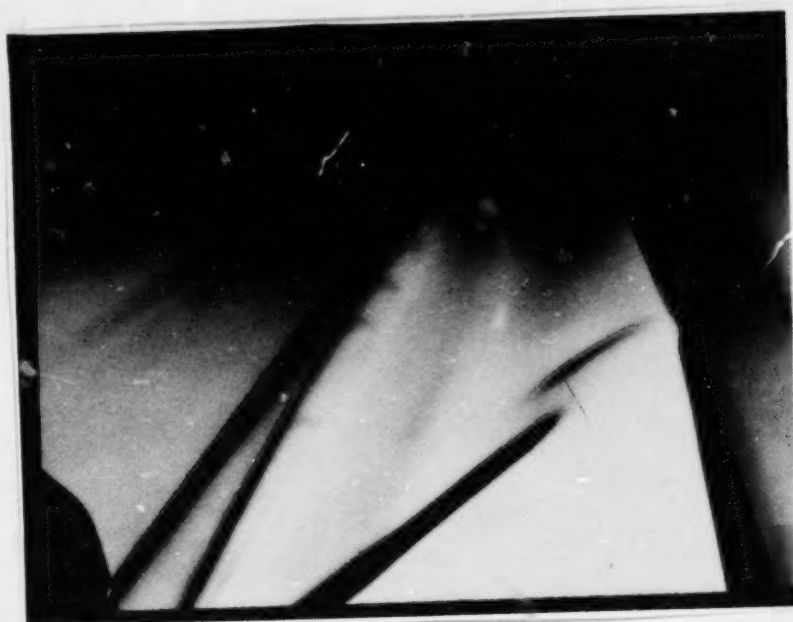


Figure 9. Pinhole formation along fold lines.

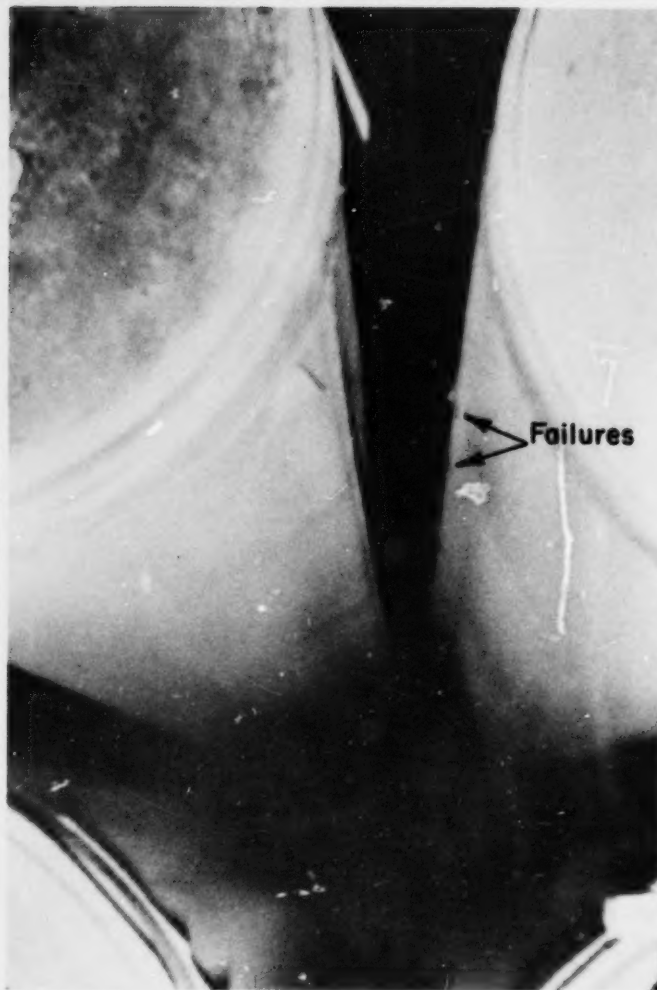


Figure 10. "Wooley worm" failure.

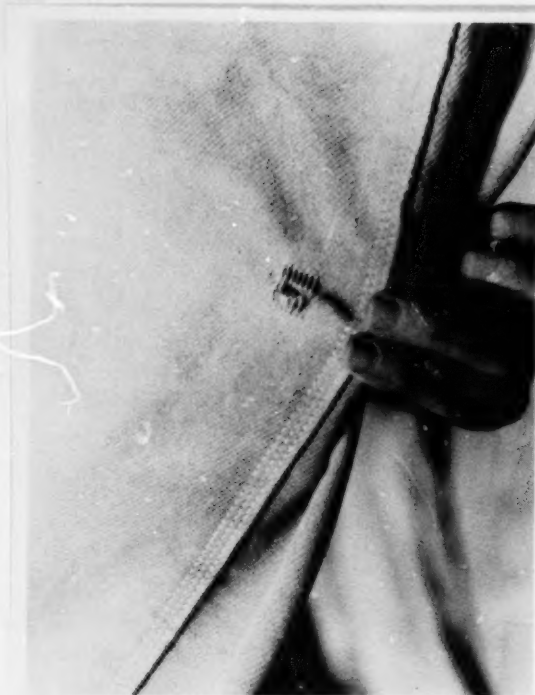


Figure 11. Horizontal tear.

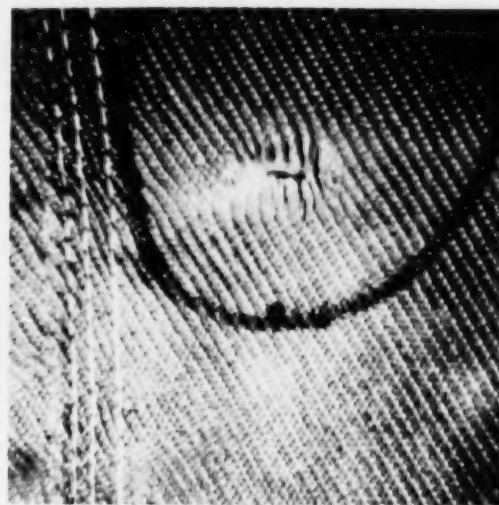


Figure 12. Horizontal tear
(closeup).



Figure 13. Vertical slit.

gave rise to speculation that the shaking forces were causing the warp yarn to fail due to greater flexure at given points in the standing wave imparted to the fabric during cleaning.

Another explanation points to the failure and consequent removal of a section of fill yarn which then leaves the dust "blasting" the warp yarns in half, causing the appearance of a horizontal slit in the fabric. Eventually, the fabrics undergoing this type of wear will experience a blowout type failure due to weakening along these flex lines. The 10-oz. Teflon-finished fabrics show evidence of this same failure type but the results have been much more evident on the heavier fabrics. Figure 13 shows a typical example where the fabric has simply slit along the fold. This is the prevalent failure type for Criswell's 449-COF and 449-I580 fabrics observed at Harrington Station. In other cases, the fabric will tear out in a rectangular fashion as shown in Figure 14. This failure type is representative of failures in Criswell's 442-57DC-2 fabric.

Figure 15 shows a good example of a "mated" failure of Criswell's 442-57DC-2 fabric where one bag failed and damaged several neighbors. Figure 16 shows the total destruction of a group of bags undergoing a mated failure that was not located for some time.

E. Causes for "Wooley Worm" Failures

In order to examine the fabric damage occurring along the fold lines, the inside surface of several of the fabrics was examined. Figure 17 shows the inside of a fabric fold line along which massive fiber breakage had occurred. In this photograph, two strips can be seen along which fiber damage appears to have occurred, possibly from being rubbed together. Microscopic examination shows very little damage in the fabric up to the edge of these lines and massive fiber breakage in the damaged zone. Figure 18 shows a destroyed yarn in the fabric at high magnification.

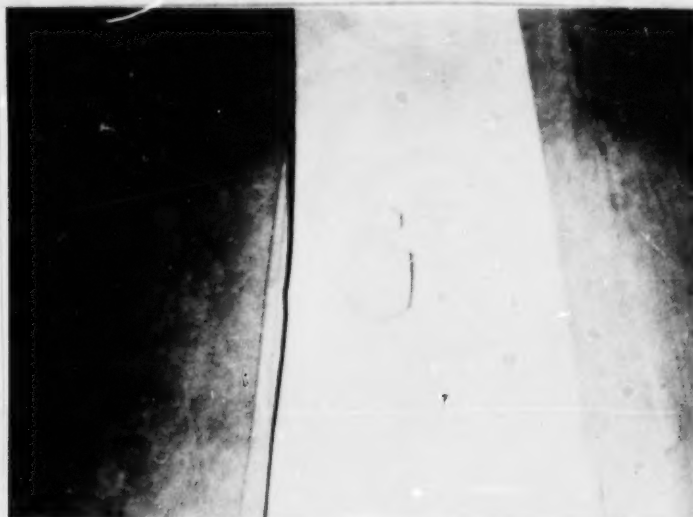


Figure 14. Rectangular failure.



Figure 15. Mated failure.

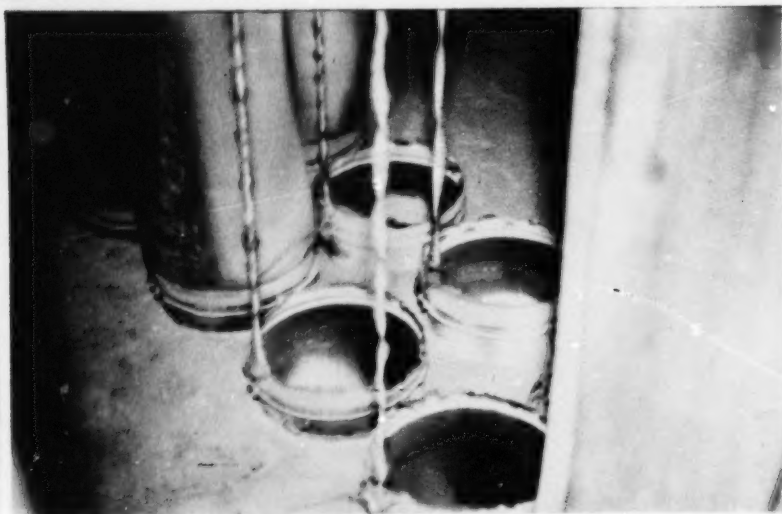


Figure 16. Total destruction by mated failure.

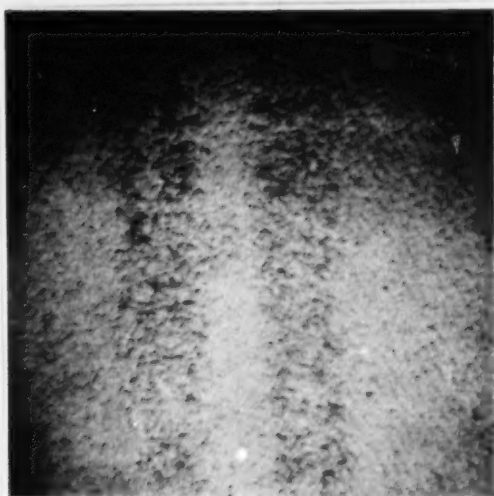


Figure 17. Fiber damage along fold lines.



Figure 18. Fiber breakage (magnified).

Figure 19 shows the inside surface of a bag that has been dissected in the neighborhood of a slit-type failure. The actual tear in the fabric is shown in Figure 19. Further down from the slit, the highly damaged area along the fold line can be observed. Figure 20 shows a close-up of the damaged fibers on this fold line.

The fact that these damaged areas have appeared commonly on the fabric in the form of both single and closely spaced double strips suggests that the fabric is being folded and flexed during the shaking process. In order to more closely observe the motion of the fabric during the shaking process, SPS decided to conduct an experiment in the EPA pilot baghouse currently in operation at Harrington Station (4). All six of the bags in one of the pilot unit compartments were removed and replaced with one unused Criswell 442-57DC-2 fabric and one unused Criswell 449-1580 fabric. The effect of the shaking process on these fabrics was then viewed by entering the compartment at both the lower and upper levels. The motions of the fabric were complex; however, it was clearly apparent that the shaking forces were responsible for causing folding and flexing along certain lines in the fabric.

The two fabrics appeared to have somewhat different reactions to the shaking forces. The 10-oz., Teflon-coated material seemed to transmit the intensity of shake further down the fabric than did the 14-oz. material. By comparison, the heavier fabric reacted to the same shaking forces in a more sluggish and lethargic manner than the lighter material. The 10-oz. Teflon-coated fabric seemed to have a very "live" reaction to shaking. The degree to which flexing occurred in the cloth was also different for the two fabrics. The relatively limp 14-oz. material appeared to be undergoing a more severe folding action while the rigid Teflon-coated fabric tended to resist the folding forces.

It is felt that this difference in reaction to the shaking forces may play the principle role in the premature failure of the 449 fabrics



Figure 19. Fold line.

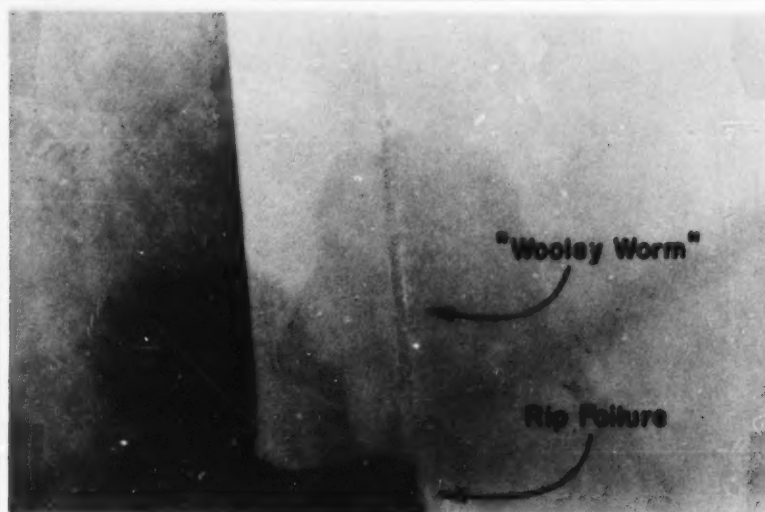


Figure 20. Closeup of "wooley worm" wear.

installed at Harrington Station. The more rigid Teflon coating may be protecting the fabric by mechanically restricting its motion during the cleaning cycle. The reaction of fabric to the forces employed during cleaning is undoubtedly one of the most important factors in determining fabric life. Further studies of this type are planned for the pilot unit in order to better define the reaction of various fabrics to shaking forces and its relation to fabric wear.

F. Relative Flow

An acceptable filtration fabric should have a high resistance to mechanical wear and chemical attack. In addition, a filtration fabric should also have adequate flow characteristics.

Throughout the fabric testing program, periodic measurements have been made of the flow characteristics for each of the test fabrics by recording the pressure drop across a manometer whose taps were located on either side of the outlet damper. These data have been used to calculate the flow through a given compartment relative to the average compartment flow. The relative flow number (compartment flow divided by average compartment flow) has the advantage of not changing value if the load on the baghouse is not the same for each measurement. Relative flow values greater than 1.0 indicate better than average flow through the compartment and values less than 1.0 indicate less flow. Since no significant trends have been observed in the relative flow data, the averages have been taken for each of the test fabrics and are presented in Table VI. Shown also in Table VI is the average of all the as received permeability measurements made on the test fabrics.

The Criswell 442-57DC-2 fabric has adequate flow characteristics as seen from Table VI, and is the basis for comparison with the other fabrics. The Menardi-Southern 601-T is not significantly different in relative flow and permeability from the Criswell 442-57DC-2 fabric. Although the relative flow and permeability data for Criswell's 449-1580

is also not significantly different from the Criswell 442-57DC-2 material, the premature failure of the fabric must be kept in mind. The 14-oz. Teflon-coated fabric (Criswell 449-57DC-2) has lower values for both relative flow and permeability indicating that the thru-put for this fabric is less desirable. The mechanical testing of this fabric, however, indicates that it may have superior life which could offset this advantage in certain applications.

Table VI. Averages of Relative Flow and Permeability

Bag Manufacturer	Style	Relative Flow	Permeability
Criswell	442-57DC-2 (10 oz/yd ² , Teflon)	1.00	1.63
Menardi-Southern	601 T (10 oz/yd ² , Teflon)	1.03	1.72
Criswell	442-57DC-2 (10 oz/yd ² , Teflon)	0.91	1.44
Criswell	449-1580 (14 oz/yd ²)	0.98	2.05
Criswell	449-COF (14 oz/yd ²)	0.92	1.78
Criswell	442-57DC-2 Warp-in (10 oz/yd ² , Teflon)	0.89	2.73
Globe-Albany	Nomex all spun (5.5 oz/yd ²)	1.27	3.01

Criswell's 449-COF fabric is shown to have lower relative flow than the other fabrics and an average value for as-received permeability. This fabric is also one that failed prematurely at Harrington Station.

The warp-in fabric has the lowest relative flow of any of the fabrics, indicating the poorest thru-put characteristics. The as-received permeability is high because of loss of cake from the bag surface which occurs due to the lack of a texturized surface. The warp-in fabric appears to be in even better mechanical condition than the warp-out fabrics but its low thru-put characteristics tend to rule out further use of this fabric at Harrington Station.

The Nomex is shown in Table VI to have remarkable thru-put with 27% higher relative flow than Criswell's 442-57DC-2. In addition, this material has 1-1½ inch w.g. less pressure drop than the other fabrics when the unit is at high load.

V. OPERATION AND MAINTENANCE

Operation and maintenance (O&M) problems during the third year of the fabric filter study fell into four main categories. The first category involved shaker flange bearings. Replacement of each of the bearings with a pillow block design is presently underway. The original shaker tube flange bearings were insulated and lagged. As a result, high temperatures, in conjunction with problems of thrust on the bearings caused by wall movement, damaged all 336 flange bearings. Replacement of the bearings has proved to be very time consuming and by the end of the year, only 22 compartments had been fitted with the pillow block design.

The second category of O&M problems had to do with sagging shaker tube support members, which were observed during the annual overhaul. Turnbuckles were used on the duct wall to provide additional support and to straighten the yielding members. After start-up, however, five compartments failed to shake due to friction in the mechanism and high bag tension caused by overtightening of the turnbuckles. Adjusting the turnbuckles eventually solved the problem.

Damper drive failures were the third main area of O&M problems. A typical failed gear nut is shown in Figure 21 and Figure 22. An increasing number of damper drive failures caused by excessive brass gear nut wear led to a meeting on March 21, 1980 between SPS, Wheelabrator-Frye, Inc. and the damper drive manufacturer. The initial result of the meeting was that screw caps were tightened and a better quality grease was used. Eventually, the manufacturer agreed that the machining of the threaded valve actuator was substandard and agreed to replace the defective units as they failed. However, the problem of damper drive failures became minor shortly after the screwcaps were tightened and lubrication with a high quality grease was initiated on a routine basis.

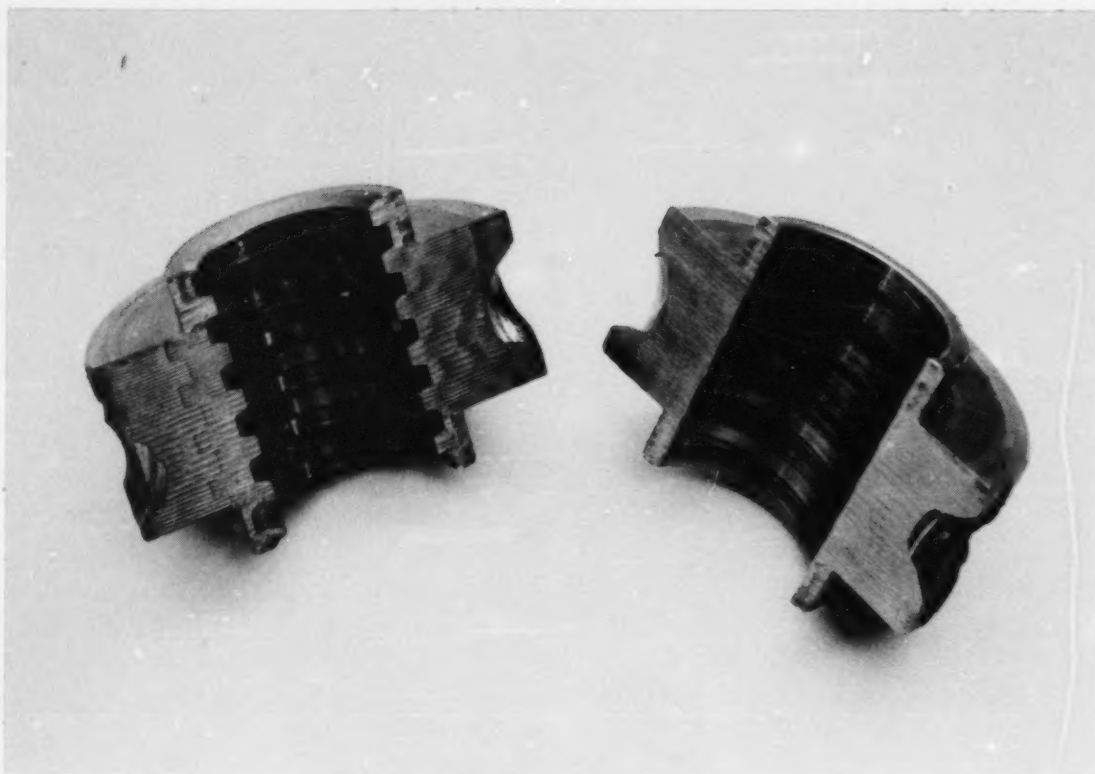


Figure 21. Typical failed gear nut (inside view).

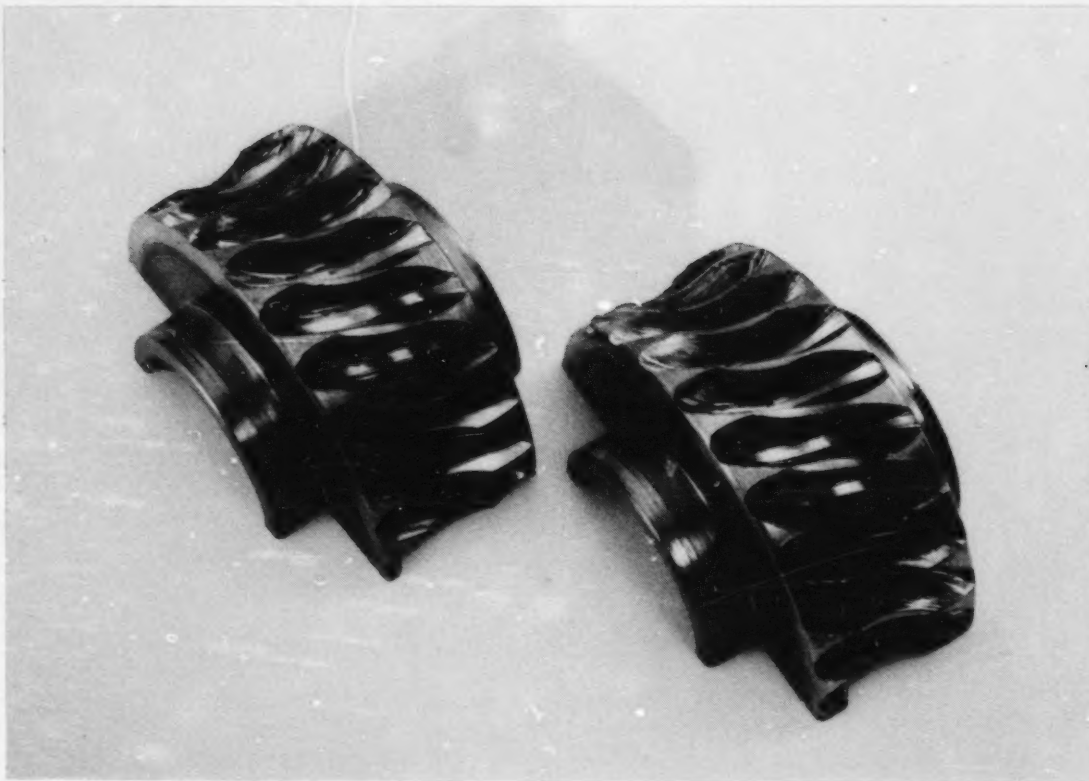


Figure 22. Typical failed gear nut (outside view).

The fourth and final category of O&M problems involved bag life. One of the fabrics that had been installed in the summer of 1979 began to show signs of failure long before the other fabrics. The failure patterns and the results of a study done on the mechanism of failure of the 14-oz. tri-coated Criswell 449-1580 is covered in another section of this report. By April, 1980, compartment 23 had such severe wear patterns and such a high failure rate that the fabric was changed during the annual outage. The remainder of the fabric, except for the 14-oz. tri-coated material, appeared to be in good condition. A 3-3½ year bag life is anticipated for several of the fabric types.

VI. PRESSURE DROP PERFORMANCE

The pressure drop performance of the baghouse can be seen in Figure 23 where the monthly average full load pressure drop for the east and west sides of the baghouse are shown. The monthly average full load pressure drop is estimated with data taken during monthly operation and represents the pressure drop expected at full load conditions. The monthly average full load pressure drops for both sides of the filter system appear to undergo normal variations, except for a 3-month period beginning in February on the west side. In April, Harrington Unit 2 was forced off line because it was not able to generate more than 250 Mw. Upon inspection of the boiler it was discovered that a slag wall had built up in the furnace arch area blocking off flow. Evidently the maldistribution of particulate and gas flow caused by this situation gave rise to the observed increase in pressure drop in the east side of the baghouse. After cleaning the furnace the east pressure drops returned to normal. This incident showed that careful characterization of baghouse performance may be useful not only in optimizing the fabric filter system but also may be valuable in indicating boiler problems.

HARRINGTON STATION UNIT 2 (BAGHOUSE) 1979-1980

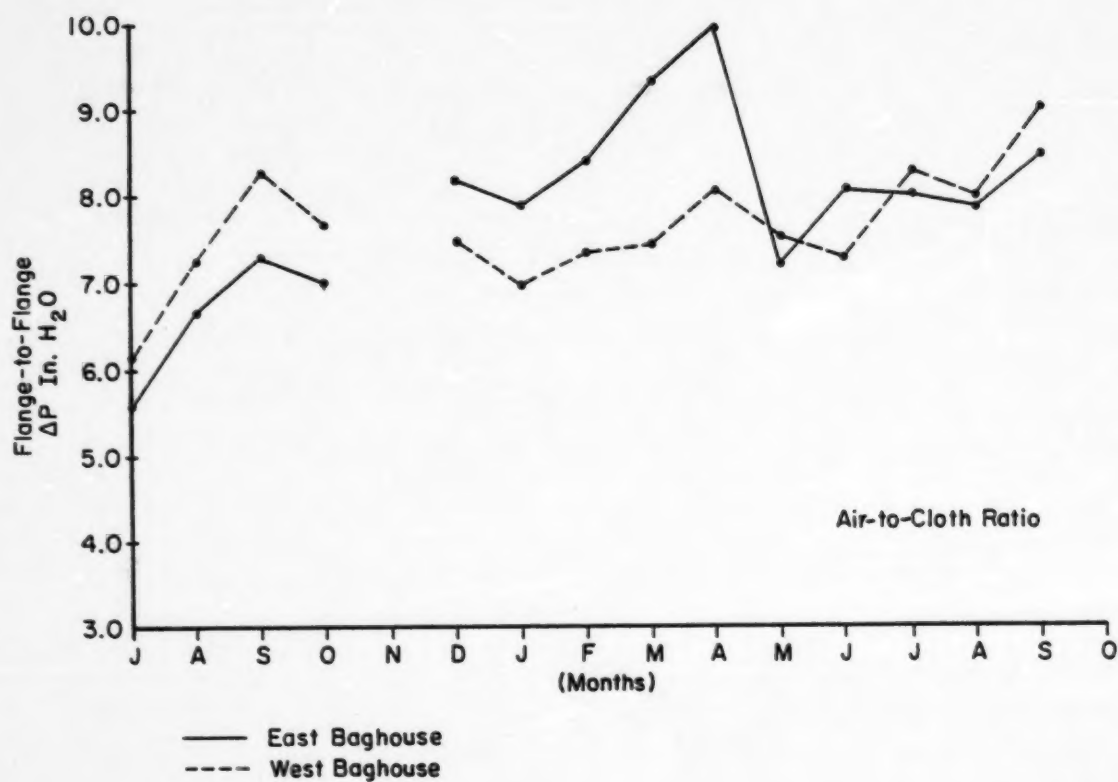


Figure 23. Monthly Average Full Load Pressure Drop

VII. OPERATION AND MAINTENANCE COSTS

The operation and maintenance costs for Harrington Unit 2 are shown in Table VII. The figures shown represent all charges against the fabric filter system, including maintenance materials, maintenance labor, operation and supervisory labor and fan horsepower.

Table VII. Operation and Maintenance Costs

Oct.	1979	\$ 34,200
Nov.	1979	31,800
Dec.	1979	36,000
Jan.	1980	37,700
Feb.	1980	34,500
Mar.	1980	29,800
April	1980	65,600
May	1980	32,000
June	1980	29,000
July	1980	38,000
Aug.	1980	35,400
Sept.	1980	<u>30,800</u>
		\$434,800

These costs were incurred during a period of operation that is not considered to be typical for several reasons. A large part of the O&M cost for this year reflected engineering design problems that are being corrected. Other atypical costs had to do with the premature fabric change-out and to some extent the higher average operating pressure drop caused by unusual boiler operating conditions from January to March.

VIII. DATA ACQUISITION AND ASSESSMENT

A. Collection of Data

Data from the instrumentation shown in Table VIII is continuously collected by computer on an hourly basis and stored on a magnetic tape system.

Table VIII. Instrumentation and Data Collection

<u>No. of Instruments</u>	<u>Type</u>	<u>Location</u>	<u>Parameter</u>
2	Annubar Flowmeter	Outlets	Flow
5	Lear Seigler CM500s Meters	Outlets, inlets, stack	O ₂
5	Lear Seigler SM800 SO ₂ /NO _x Meters	Outlets, inlets, stack	SO ₂ /NO _x
5	Thermocouples	Stack	Temperature

The goals for the analysis of this data include an analysis of how specific variables affect system pressure drop. These variables include temperature, time in service, boiler load, air-to-cloth ratio, and excess O₂.

Preliminary work involving multiple regression analysis on the collected data indicates that some of these variables cannot be assumed independent. Table IX shows the typical correlation matrix resulting from the statistical analysis for data gathered during a single month.

Table IX. Correlation Matrix

	Oxygen	Mw	(Mw)(O ₂)	Temperature	Air-to-Cloth
Oxygen	1.00000	-0.81794	-0.34700	-0.75273	-0.78042
Mw	-0.81794	1.00000	0.82339	0.81506	0.95087
(Mw)(O ₂)	-0.34700	0.82339	1.00000	0.58636	0.78029
Temp.	-0.75273	0.81506	0.58636	1.00000	0.88955
Air-to-Cloth	-0.78042	0.95087	0.78029	0.88955	1.00000

A more sophisticated statistical analysis will have to be undertaken in order to extract more information from this data.

B. Monthly Average Full Load Pressure Drop

Monthly average full load pressure drop for the year is shown in Figure 23. As discussed elsewhere in the report, close observation of the monthly average full load pressure drop continues to be of value in analyzing boiler/ baghouse problems.

The relationship between the pressure drop, ΔP_1 at air-to-cloth ratio, V_1 , can be related to the pressure drop, ΔP_2 , at another air-to-cloth ratio, V_2 by the approximate expression:

$$\frac{\Delta P_2}{\Delta P_1} = \left(\frac{V_2}{V_1} \right)^{1.35}$$

This expression holds for Harrington Station and may be applicable to filtration of ashes similar to that generated at Harrington.

IX. REFERENCES

1. Ladd, K., Faulkner, G., and Kunka, S., "Fabric Filter System Study: First Annual Report," EPA-600/7-79-183, Contract No. 68-02-2659, August 1979.
2. Ladd, K., Chambers, R., Plunk, O., and Kunka, S., "Fabric Filter System: Second Annual Report," EPA-600-S7-81-037, Contract No. 68-02-2659, August 1980.
3. Ladd, K., Plunk, O., Thurman, S., Pinson, L., Fajardo, L., Metcalf, D., and Kunka, S., "Harrington Station Unit 2 Fabric Filter System Special Testing Report," EPA-600/7-81-168, Contract No. 68-02-2659, October, 1981.
4. Ladd, K. L., Hooks, W., Kunka, S., "SPS Pilot Baghouse Operation," presented at the Third Symposium on the Transfer and Utilization of Particulate Control Technology, Orlando, Florida, March 1981.
5. Schiff, H., Piispanen, W., Bradway, R., "Baghouse Performance Test - Southwestern Public Service Company, Harrington Station Unit No. 2," GCA-TR-79-43-G, September 1980.
6. McCabe, M., Reicker, E., and Montanaro, O., "Baghouse Performance Test - Phase II, Southwestern Public Service Company, Harrington Station Unit No. 2," Final Report GCA-TR-80-70-G, September 1981.